# Multiplication noise in planar InP/InGaAsP heterostructure avalanche photodiodes

| | |
| --- | --- |
| 著者 | 中嶋　一雄 |
| journal or publication title | Applied Physics Letters |
| volume | 40 |
| number | 6 |
| page range | 532-533 |
| year | 1982 |
| URL | http://hdl.handle.net/10097/46952 |

doi: 10.1063/1.93132

GaAs FET. This finding has strong consequences in microwave and high speed logic technology.

The authors are gratefully thankful to J. P. Levy, M. Chapuis, J. Frentzel, and G. Bourrabier for technical assistance, to B. Carnez and J. P. Mutzig for microwave measurements, and to J. Massies, M. Rieux, J. L. Teszner, and G. Delaval for helpful discussions.

[1]R. Dingle, H. L. Störmer, H. L. Gossard, and W. Wiegmann, Appl. Phys. Lett. **33**, 665 (1978).
[2]H. L. Störmer, R. Dingle, A. C. Gossard, W. Wiegmann, and M. D. Sturge, Solid State Commun. **29**, 705 (1979).
[3]L. C. Witkowski, T. J. Drummond, S. A. Barnett, H. Morkoc, A. Y. Cho, and J. E. E. Greene, Electron. Lett. **17**, 126 (1981).
[4]S. Hiyamizu, T. Fujii, T. Mimura, K. Nanbu, J. Saito, and H. Hashimoto, Jpn. J. Appl. Phys. **20**, L445 (1981).
[5]H. L. Störmer, A. Pinczuk, A. C. Gossard, and W. Wiegmann, Appl. Phys. Lett. **38**, 691 (1981).
[6]T. J. Drummond, W. Kopp, and H. Morkoc, Electron. Lett. **17**, 442 (1981).
[7]T. Mimura, S. Hiyamizu, T. Fujii, and K. Nanbu, Jpn. J. Appl. Phys. **19**, L225 (1980).
[8]D. Delagebeaudeuf, P. Delescluse, P. Etienne, M. Laviron, J. Chaplart, and N. T. Linh, Electron. Lett. **16**, 667 (1980).
[9]D. Delagebeaudeuf and N. T. Linh, IEEE Trans. Electron. Dev. **ED-28**, 790 (1981).
[10]D. Delagebeaudeuf and N. T. Linh, IEEE Trans. Electron. Devices (to be published).
[11]M. Laviron, D. Delagebeaudeuf, P. Delescluse, J. Chaplart, and N. T. Linh, Electron. Lett. **17**, 536 (1981).
[12]T. Mimura, S. Hiyamizu, K. Joshin, and K. Hikosaka, Jpn. J. Appl. Phys. **20**, L317 (1981).
[13]P. Delescluse, M. Laviron, J. Chaplart, D. Delagebeaudeuf, and N. T. Linh, Electron. Lett. **17**, 342 (1981).

# Multiplication noise in planar InP/InGaAsP heterostructure avalanche photodiodes

Tatsunori Shirai, Susumu Yamasaki, Fukunobu Osaka, Kazuo Nakajima, and Takao Kaneda
*Fujitsu Laboratories, Ltd., Kawasaki 211, Japan*

(Received 1 October 1981; accepted for publication 22 December 1981)

Planar InP/InGaAsP avalanche photodiodes have been fabricated and multiplication noise is discussed. The effective hole to electron ionization rate ratio is found to be 1.9 from the wavelength dependence of multiplication noise.

PACS numbers: 85.60.Gz, 85.30.De

Multiplication noise is a key parameter in determining the performance of avalanche photodiodes (APD's) used as light detectors in optical fiber communication systems. InGaAsP APD's have been actively studied to reduce multiplication noise.[1-4] Low dark current and high avalanche gain have been demonstrated with heterostructure InGaAsP APD's whose multiplication region is formed in the InP layer, however, multiplication noise has not been studied fully. Recently, Susa *et al.* have reported on an InGaAs/InP APD.[3] Their result shows that multiplication noise is proportional to the 2.7th power of multiplication factor $M$ in the $M < 20$. Diadiuk *et al.* have reported on an InGaAsP/InP APD with excess noise factor $F$ of $\sim 3$ at $M = 10$.[4] This $F$ value corresponds to the 2.48th power of $M$. The agreement between these results is not good. These studies were carried out by using diodes with a mesa structure. Diodes with uniform and high avalanche gain ($M > 100$) are required for studying multiplication noise, however, it is difficult to achieve these characteristics with devices of a mesa geometry due to the field concentration in the peripheral region of the junctions. In this letter, we describe the first results on multiplication noise in planar InP/InGaAsP APD's.

A planar diode with a guard ring has been made by using a two-step guard ring structure fabricated by $Be^+$ implantation and carrier concentration difference of top InP layers. The schematic structure is shown in Fig. 1. The fabrication procedure is similar to that previously described.[5] The photoresponse at 1.3-$\mu$m wavelength is shown as a function of the bias voltage in Fig. 2. Since the incident light of $\lambda = 1.3\ \mu$m was absorbed only in the $n$-type quarternary layer, a pure hole injection into the multiplication region ($n$-InP) was realized. The photoresponse was not observed until the $n$-InP layer was just depleted. The onset of the response at about 20 V corresponds to the punchthrough of the depletion region from $n$-InP into the quarternary layer. The voltage dependence of the photoresponse was not obtained in the voltage region of 25–45 V, indicating that the multiplication factor in this voltage region is unity. The maximum avalanche gain was 110 at an initial photocurrent of 0.35 $\mu$A. The quantum efficiency at 1.3 $\mu$m was about 50% without

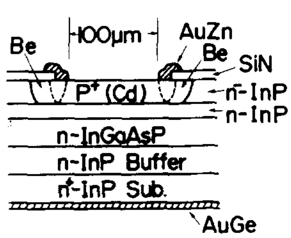


FIG. 1. Cross-sectional view of the diode.

  

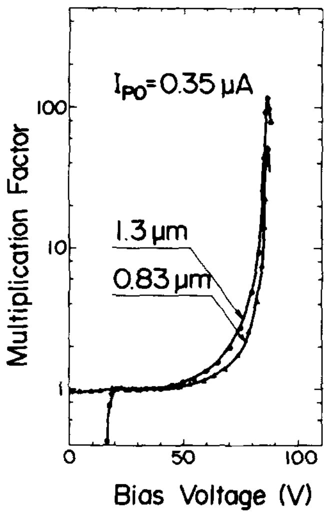


FIG. 2. Voltage dependence of multiplication factors.

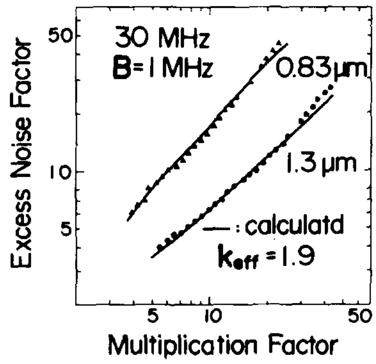


FIG. 3. Excess noise factors as a function of multiplication factor. At the 0.83-$\mu$m wavelength—pure electron injection, at 1.3 $\mu$m—pure hole injection.

an antireflection coating.

Multiplication characteristics at 0.83 $\mu$m were also studied. In this case, a pure electron injection was achieved, since the skin depth for this[6] wavelength ($\sim 0.5\ \mu$m) is shallow enough compared with a junction depth (2 $\mu$m). The maximum gain obtained was 53 at the same initial photocurrent, and was smaller than that of 1.3 $\mu$m. This shows that the ionization rate for holes is greater than that for electrons in InP. The maximum gains obtained were large enough to study multiplication noise in the multiplication region of 10–30 which is the optimum range in the optical communication systems. The spot-scanned photoresponse of the diode was studied at $M = 15$ by using an InGaAsP laser diode (1.3 $\mu$m). Uniformity of photoresponse in the active region was good for studying multiplication noise.

Multiplication noise was studied at two wavelengths of incident light (0.83 and 1.3 $\mu$m) to obtain pure electron and hole injections into the multiplication region. Excess noise factors studied at 30 MHz with a 1-MHz bandwidth are shown in Fig. 3. The solid line in this figure show the calculated results from McIntyre's equation[7] in both cases of pure electron and hole injections. The experimental results agree reasonably well to the calculated ones, using the hole to electron effective ionization rate ratio $k_{\rm eff}$ of 1.9. This $k_{\rm eff}$ is found to be in close agreement with the previous results in InP,[8,9] and is larger than that of germanium APD ($\sim 1.4$).[10]

In conclusion, planar InP/InGaAsP APD's having an uniform and high avalanche gain at 1.3-$\mu$m wavelength have for the first time been fabricated for studying multiplication noise. Excess noise factors obtained are found to be in a good agreement with the calculated results using the hole to electron effective ionization rate ratio of 1.9.


The authors would like to thank T. Ikegami and T. Kimura in NTT for their continuing guidance and encouragement. They would also like to acknowledge useful discussions with T. Sakurai, K. Akita, and T. Mikawa.



[1]M. Ito, T. Kaneda, K. Nakajima, Y. Toyama, T. Yamaoka, and T. Kotani, Electron. Lett. **14**, 418 (1978).
[2]F. Osaka, K. Nakajima, T. Kaneda, T. Sakurai, and N. Susa, Electron. Lett. **16**, 716 (1980).
[3]N. Susa, H. Nakagome, O. Mikami, H. Ando, and H. Kanbe, IEEE J. Quantum Electron. **QE-16**, 864 (1980).
[4]V. Diadiuk, S. H. Groves, and C. E. Hurwitz, Appl. Phys. Lett. **37**, 807 (1980).
[5]T. Shirai, F. Osaka, S. Yamasaki, K. Nakajima, and T. Kaneda, Electron. Lett. **17**, 826 (1981).
[6]H. H. Wieder, A. R. Clawson, and G. E. McWilliams, Appl. Phys. Lett. **31**, 468 (1977).
[7]McIntyre, IEEE Trans. Electron. Devices **ED-13**, 164 (1966).
[8]I. Umebu, A.N.M.M. Choudhury, and P. N. Robson, Appl. Phys. Lett. **36**, 301 (1980).
[9]T. Shirai, F. Osaka, S. Yamasaki, and T. Kaneda, Appl. Phys. Lett. **39**, 168 (1981).
[10]S. Kagawa, T. Kaneda, T. Mikawa, Y. Banba, and Y. Toyama, Appl. Phys. Lett. **38**, 492 (1981).